

TITLE: AUTOMATIC DETECTION OF ALTERATIONS IN PULMONARY
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SUBMITTED TO: To be published in the Proceedings, San Diego
Biomedical Symposium, Feb. 2-4, 1977.

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AUTOMATIC DETECTION OF ALTERATIONS IN PULMONARY VENOUS PRESSURE

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ABSTRACT

Image processing and pattern recognition techniques are useful in radiology to aid in the decision making process involving disease patterns in radiographs. The long range goal of this study is to develop a completely automated computer controlled optical system for early detection and classification of prepulmonary edema. This is achieved from chest x-rays by observing and measuring certain patterns of lung vascularity which enable us to characterize the presence and severity of the disease. The lung vascularity patterns were extracted using the Fraunhofer diffraction pattern sampling unit which samples the Fourier transform and obtain the spatial frequency measurements. A laser is used to illuminate certain zones of the lung, and by passing the image through a thin convex lens the diffraction pattern is produced. This pattern impinges on a sensor composed of 32 annular rings and 32 angular wedges which sample the squared modulus of the diffraction pattern and produces the annular ring and wedge regions of the transform space. It has been shown that with an increase in pulmonary venous pressure there is a redistribution of blood flow in the lungs. This redistribution will affect the number of vessels in the upper zone as compared to the number of vessels in the lower zones of the lung and thus change the ring and wedge signatures. Measurements of the ring and wedge signatures have been made on a number of chest radiographs which had been classified by the Turner method as to the presence and extent of pulmonary edema. The measurements were used to train a linear classifier program, i.e. to calculate coefficients which allow the program to automatically classify new cases. Preliminary results indicate a classification accuracy on the training data of 90%.

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INTRODUCTION

Pulmonary edema is a pathological state in which there is abnormal extravascular storage of fluid in the lung. In the normal lung, fluid which enters the extravascular space is removed by lymphatic and capillary drainage. Fluid accumulates within the lung when hydrostatic pressure in the pulmonary capillaries becomes greater than the plasma oncotic pressure; the capacity for the lymphatic drainage is exceeded; or the permeability of pulmonary capillaries is increased.

Cardiogenic pulmonary edema is the major form of pulmonary edema and results from an elevation of the pulmonary venous pressures in excess of the plasma oncotic pressure, and as a result, fluid leaves the vascular compartment and escapes to the extravascular lung spaces. With the methods presently available, pulmonary edema can only be detected late in its course clinically, making prompt therapy of the developing condition impossible, and contributing to its morbidity and mortality.

It has been shown experimentally that as the pulmonary venous pressures rise, there is redistribution of blood flow within the lungs due to perivascular edema/1/. Friedman and Braunwald/2/ have shown by radioisotope studies that the magnitude of the shift of flow, from the lower to upper lung zones, has a linear relationship to the mean left atrial (pulmonary venous) pressure.

Turner et al/3/ classified the magnitude of shift from the lower to the upper lung zones utilizing the routine chest radiograph. It was noted that in the normal upright full-inspiration chest radiograph, flow is directed to the lower lung zones by gravity. As a result the size and number of vessels per unit area in the lower lung zone is greater than the size and number of vessels in the upper zones in the upright position. Normal pulmonary vessels show an orderly tapering and branching toward the periphery, where they become invisible in the subpleural regions of the lung. When pulmonary venous pressures rise there is a redistribution of pulmonary blood flow. This was graded from 1+ to 4+ by Turner et al/3/.
1+ redistribution: is present when there is equal perfusion of the upper and lower lung zones, and the increase in perfusion of upper zones is due to shifting of blood from the lower zones.
2+ redistribution: is present when there is

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greater perfusion in the upper than the lower lung zones. This represents an inversion of the normal pulmonary blood flow pattern. 3+ redistribution: is present when 2+ redistribution is accompanied by changes of interstitial edema. Interstitial edema is manifest by one or more of the following: perihilar indistinctness, perivascular indistinctness, peribronchial indistinctness, subpleural edema, septal lines (Kerley B), over-all haziness of lower lung zones (Kerley C) and outward shift of lower lobe vessels. 4+ redistribution: is represented by alveolar edema.

Pulmonary venous pressures were assigned by Turner et al/3/ to five stages of vascular redistribution and are summarized in the following table.

Redistribution Pattern	Mean Pulmonary Venous Pressure
Normal	5 - 10 mm Hg
1+	10 - 15 mm Hg
2+	15 - 25 mm Hg
3+	25 - 35 mm Hg
4+	greater than 35 mm Hg

Chest radiographs of patients with normal and elevated pulmonary venous pressures have been graded according to the Turner criteria, and these were correlated with cardiac catheterization data.

If pulmonary vascular redistribution can be measured and utilized to grade the level of pulmonary venous pressure, then an automated technique could be used to screen large numbers of films. Early detection of elevations in pulmonary venous pressure could allow the institution of early treatment with the prevention of pulmonary edema. This early treatment should reduce both the morbidity and mortality.

Automated measurements would be consistent in time and as such there would be intra or inter-reader variation, and patients could be followed under treatment to assess efficiency of a treatment regimen.

EXPERIMENTAL APPROACH

Instead of trying to diagnose cases on the basis of direct measurements of the chest radiographs, we have chosen to look at the Fourier transform of two zones in the right lung, one in the upper half of the lung and one in the lower half. Here the Fourier transform F is a two-dimensional transformation on the spatial coordinates

$$Z(\alpha x, \beta y) = \iint f(x', y') \exp(-2\pi i \alpha x' + \beta y') dx' dy'$$

where $f(x', y')$ is the amplitude transmittance function of the chest radiograph, $i = \sqrt{-1}$, and α is a constant which depends upon system parameters. The reason for looking at Fourier transform data is that the differences we are trying to detect are of a global rather than a localized nature. Each point in the Fourier transform space contains information about the spatial frequency content of the entire image. Thus measurements made in Fourier space are global measurements which should be related to the global changes we wish to detect. Cardiogenic pulmonary edema manifests itself through the appearance of increased vascularity in the upper lung field. This increased vascularity should be reflected in a shift of the energy distribution in the Fourier transform plane, e.g. a relative increase in the high spatial frequency content.

Since the main characteristic of pulmonary edema that we wish to detect is a redistribution of vascularity, a shift from the lower lung to the upper lung, measurements are made of the Fourier transforms for two zones: one in the upper half of the right lung and one in the lower half. Figure 1 shows the two zones of the lung field which were used for measurements.

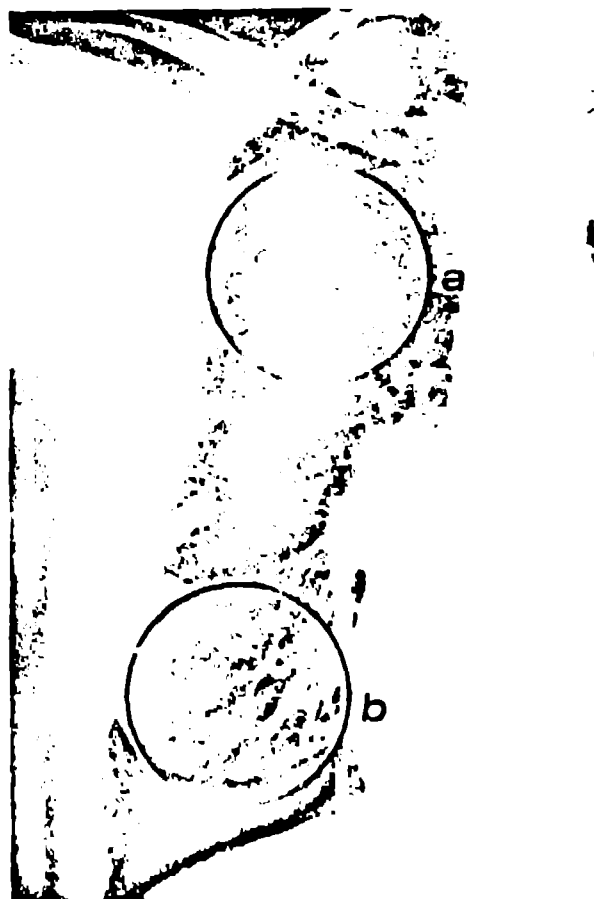


Figure 1. Measurement zones in the chest radiograph. Circle A - upper lung zone. Circle B - lower lung zone.

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MEASUREMENT SYSTEM

It has long been known that a two-dimensional Fourier transform can be performed by a relatively simple optical system /4/ such as the one in Figure 2.

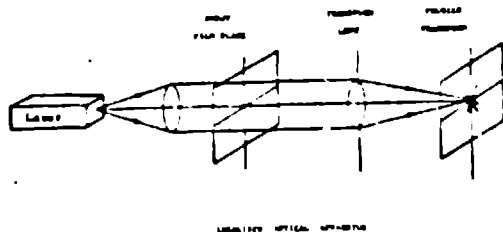


Figure 2. Optical Fourier transformation system.

The optical approach to Fourier transformation is advantageous because of its relatively low cost and its extremely high speed. An inexpensive lens can be used to perform a two-dimensional Fourier transform on a large array (e.g. 10^6 elements) in a nanosecond. This speed is totally unapproachable with a digital computer. In this experiment each of the two zones in the lung contained over 10^5 picture elements. These two zones were individually Fourier transformed and the transforms were sampled with a 64 element detector manufactured by Recognition Systems, Inc. The arrangement of the detector elements is shown in Figure 3.

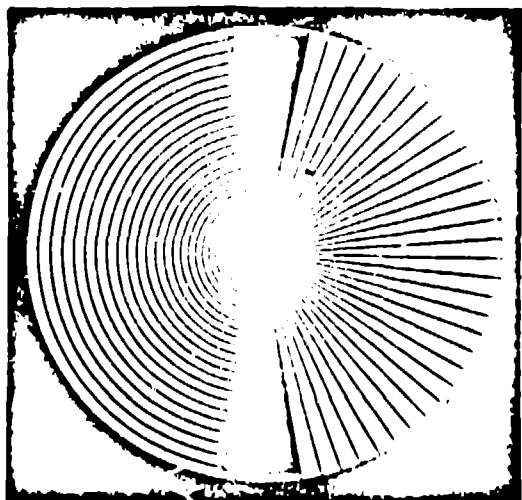


Figure 3. RSI detector configuration.

This configuration was especially designed for sampling Fourier transforms. There are 32 annular segments which provide information about the spatial frequency content of the image, independent of orientation. These are complemented by 32 wedge-shaped elements which provide information on the angular distribution of energy, independent of spatial frequency distribution. The utility of this detector rests in part upon the assumption that the diffraction pattern is radially symmetric. This will be true if the chest radiograph is free of any variations which would affect the phase of the coherent illumination in the optical Fourier transform system. This condition is not strictly satisfied. In particular such things as fingerprints and scratches in the film give to phase variations which add a certain amount of noise to the measurements. The extent and severity of this noise is currently under study.

DATA ANALYSIS

The measurement system produces 64 measured values or features for each of the two lung zones. These measurements are collected for a series of chest radiographs for which data is also available on the patient's pulmonary venous pressure. The measurements are then used to "train" a computer classification program. That is, the computer is given the measurements for each chest radiograph along with the known pulmonary edema classification. The computer algorithm takes this data and does two things. First is a feature extraction: from all the measurements on a given lung zone (e.g. 64) the algorithm chooses a set number of features which show the best differentiation between normal and abnormal cases. Secondly, the algorithm looks for a set of coefficients for the chosen features which provide optimum separation of the normals from the abnormals.

Two different classification algorithms were used. The first program was BMD07M which was developed at UCLA at The Health Sciences Computing Facility. This program classifies the data using a linear combination of the measurements. A quadratic classifier has also been tried. This second classification algorithm was written by Dr. W. B. Thompson of the University of Minnesota.

A more complete description of the measurement system and the classification approach can be found in a paper by Kruger, et.al./5/.

RESULTS

Initial work has concentrated on separating two classes: normals and those classified as 2+ according to the Turner classification scheme. Detection of pulmonary edema at the 2+ stage would allow treatment which should significantly reduce morbidity and mortality.

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Figure 4 shows examples of the routine chest radiographs for: a normal (4A) case and a 2+ redistribution (4B).

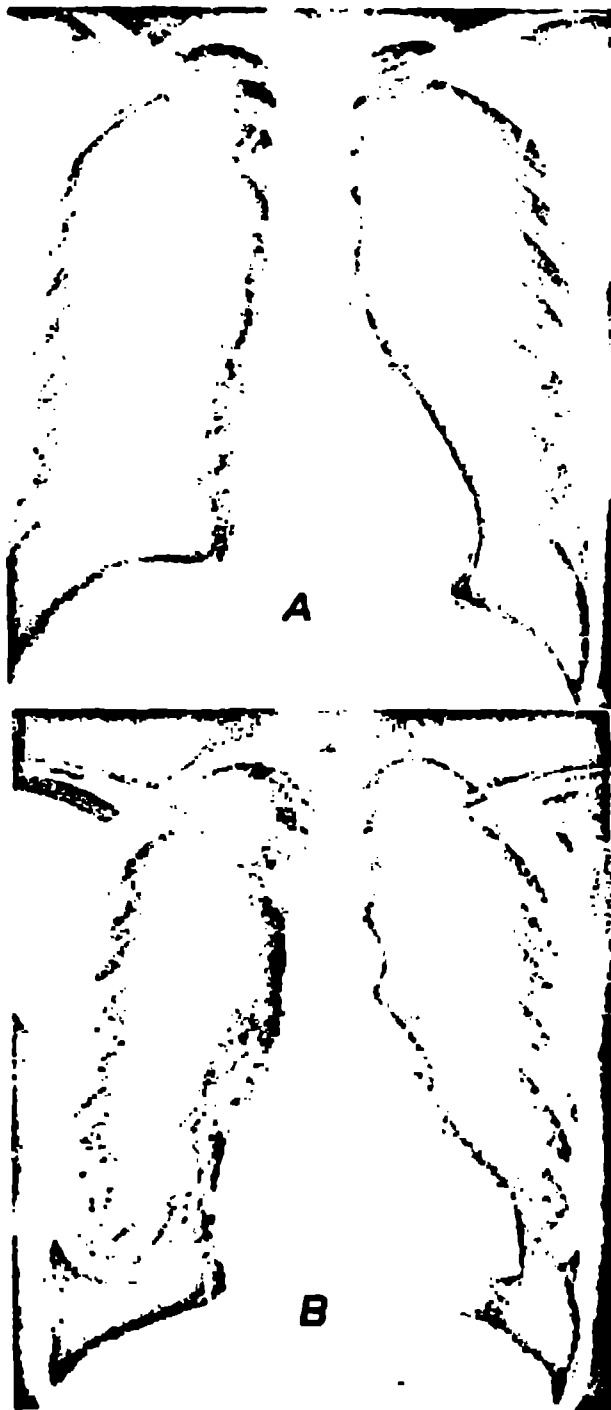


Figure 4. (A) Chest radiograph - normal vascularity. (B) Chest radiograph 2+ vascular redistribution.

Although it is not readily apparent to the untrained eye, the 2+ case shows a relatively

larger number of vessels in the upper lung field than in the normal case. This redistribution is more readily apparent in the angiograms shown in Figure 5. Angiograms obviously afford a ready means of classification but they represent an invasive technique which should be avoided.



Figure 5. (A) Pulmonary angiogram (arterial phase) normal vascularity. (B) Pulmonary angiogram (arterial phase) 2+ redistribution of vascularity.

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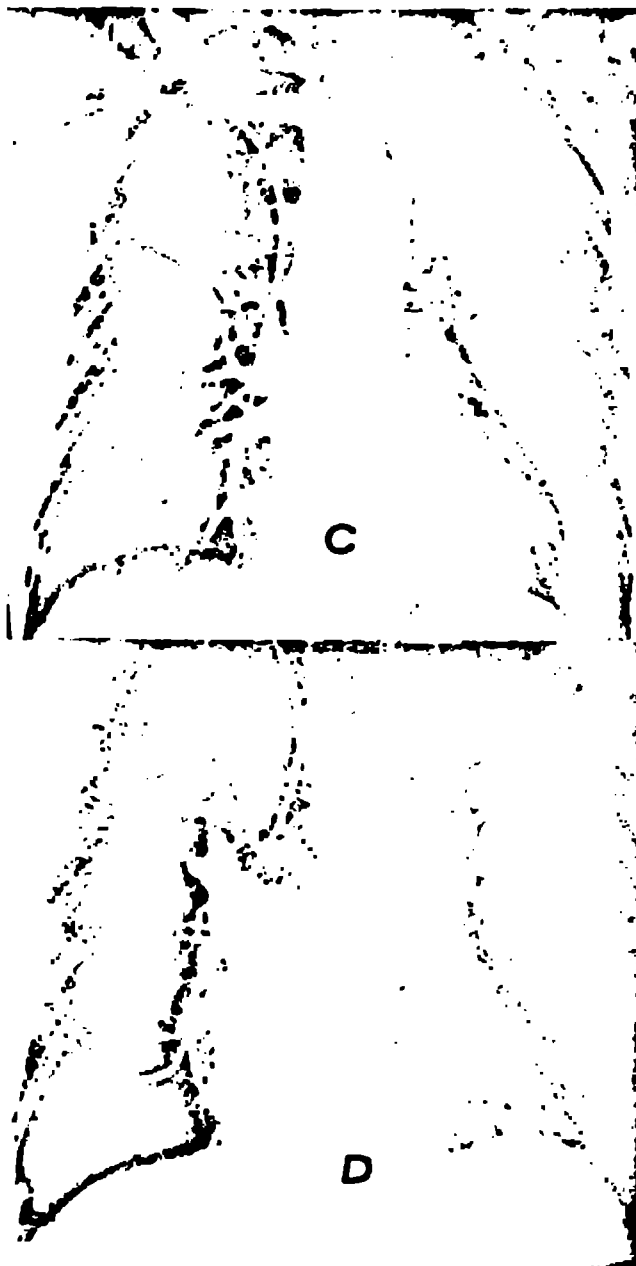


Figure 5. (C) Pulmonary angiogram (venous phase) normal vascularity. (D) Pulmonary angiogram (venous phase) 2+ redistribution.

A set of chest radiographs were selected from the files of the Los Angeles County-University of Southern California Medical Center. Cardiac catheterization results were available on all selected cases.

The data base of selected cases was composed as follows

Classification	No. of cases
Normals	59
1+	2
2+	75
3+	87
4+	2

For the preliminary work only the normals and 2+ cases were used. These were further screened to eliminate markedly special cases. Training was thus done using 59 normals and 52 2+ redistributions. The BMD program was used to train on this data base in three different ways: 1) by comparing upper zones of normals to upper 2+ zones; 2) by comparing normal lower zones to 2+ lower zones; 3) by taking the ratios of upper zone measurements to lower zone measurements and comparing these for normal and 2+ redistribution. In each case, 10 of the 64 measurements were selected for use in classification. After the training procedure each of the three comparisons generated a set of a posteriori probabilities for each patient. These indicate the probability of a given patient being either normal or 2+ redistribution. By averaging the a posteriori probabilities from each of the three comparisons, a classification accuracy of 90% was obtained for the training data set. The classification matrix was as follows:

		True Class	
		Normal	2+
Assigned Class	Normal	54	7
	2+	5	45

No attempt at this time has been made to minimize the number of false negatives, i.e. cases which were actually 2+ but classified as normal. Some tests were made with the quadratic classifier which generally gave one to two percent improvement in classification over the BMD routine.

It should be reiterated that these are training results and that jackknife testing procedures are being developed now to validate the results.

CONCLUSIONS

An attempt has been made to detect pre-pulmonary edema by doing classification on the spatial frequency distribution of chest radiographs. Initial training results showed

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a 90% classification accuracy which indicates the viability of this approach to doing automatic detection of pre-pulmonary edema (elevation of pulmonary venous pressure).

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